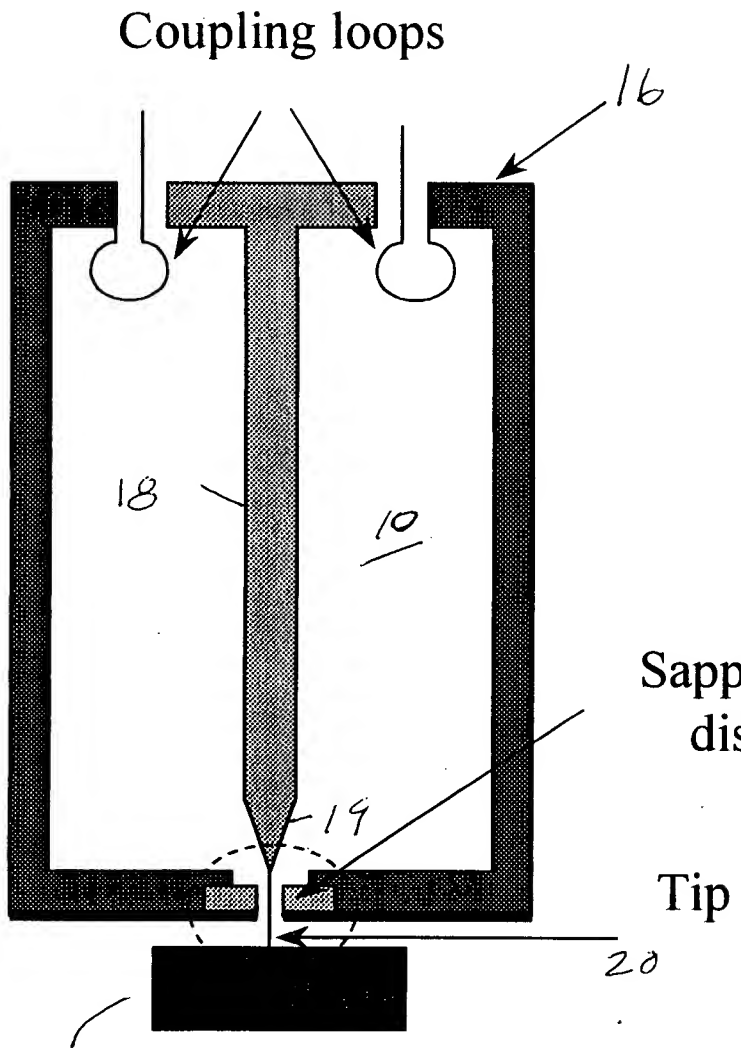


FIG. 1(A)

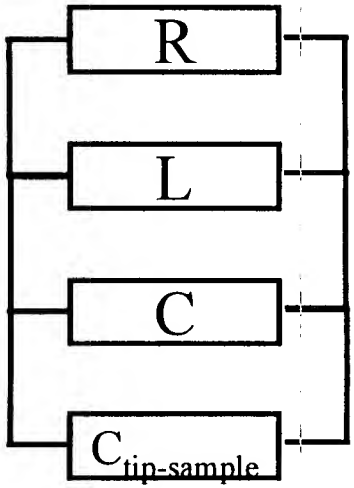


FIG. 1(B)

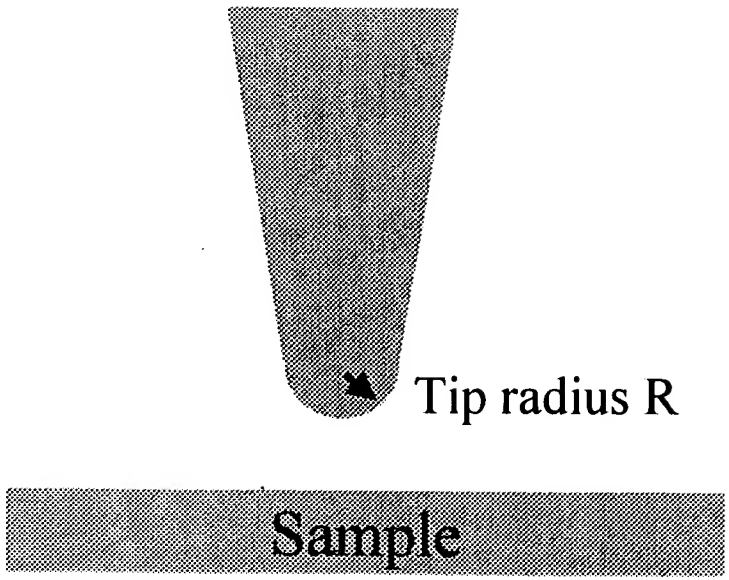


Fig. 2

Calculation

Since $\lambda >> R_0\sqrt{|\varepsilon|}$

The field distribution is approximately quasi-static and can be calculated by the method of images.

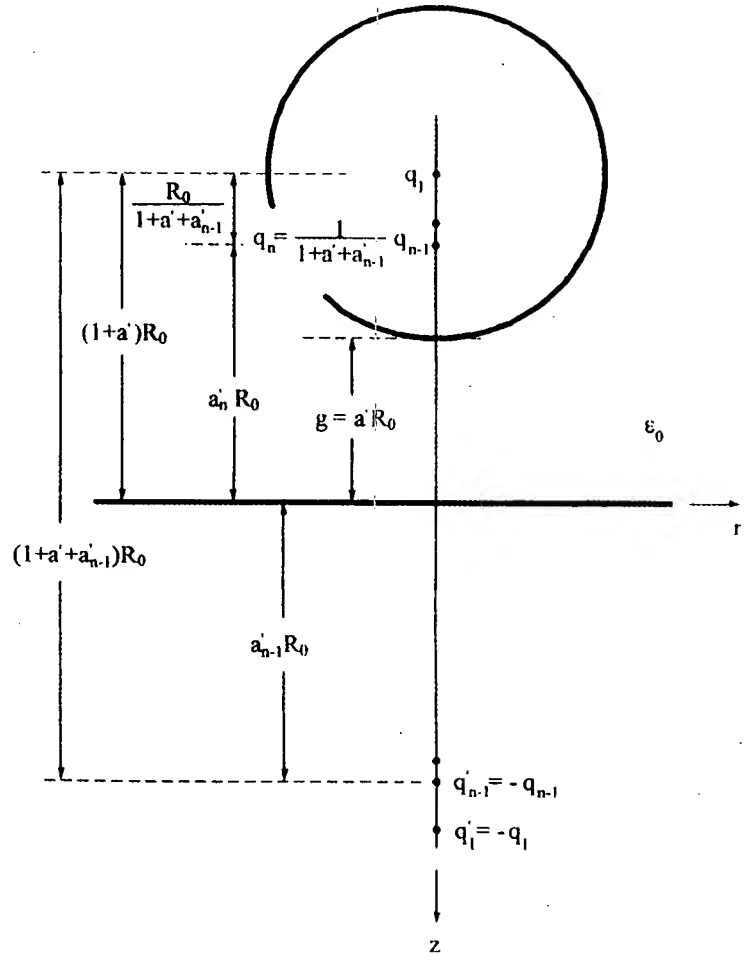


Fig. 3

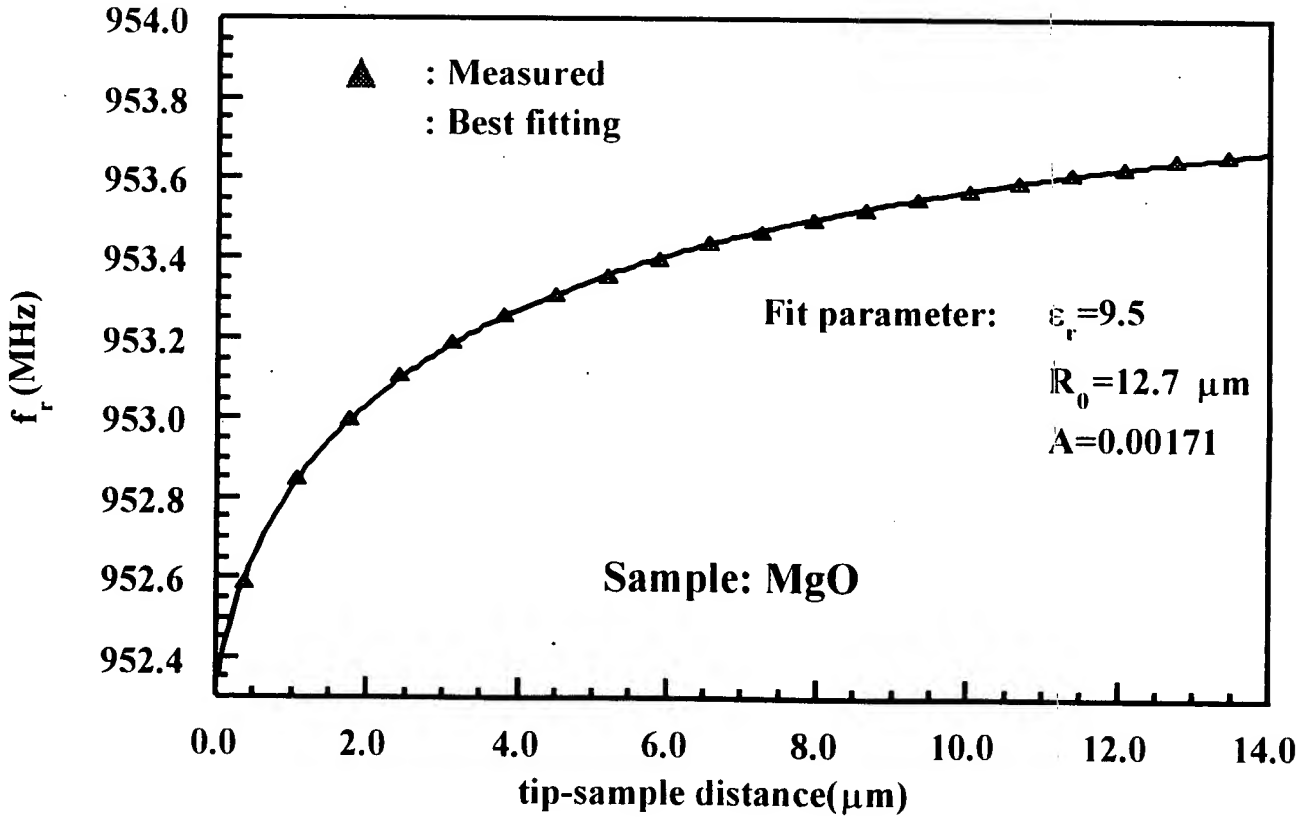

954.0
953.8
953.6
953.4
953.2
953.0
952.8
952.6
952.4
f_r (MHz)
: Measured
: Best fitting
Fit parameter: ε_r=9.5
R_0=12.7 μm
A=0.00171
Sample: MgO
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
tip-sample distance(μm)

Fig. 4

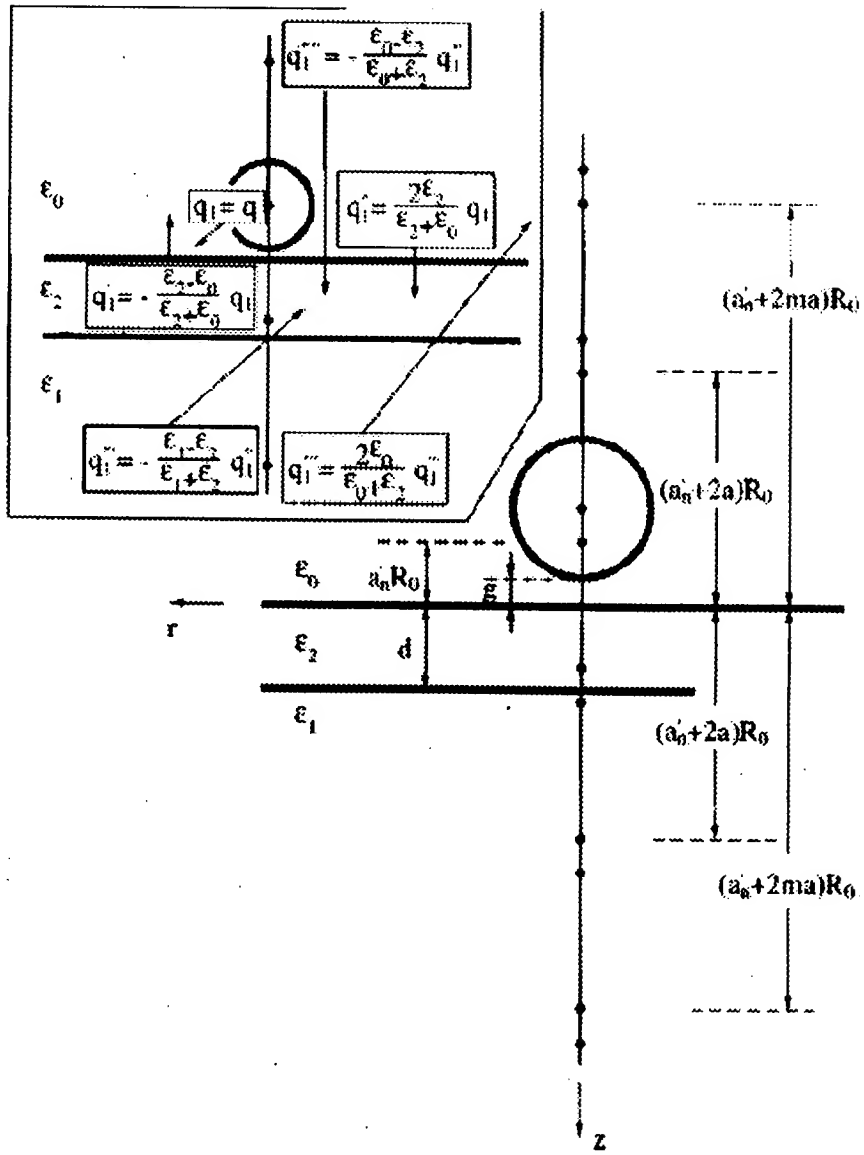

$q_1''' = -\frac{\varepsilon_0-\varepsilon_2}{\varepsilon_0+\varepsilon_2} q_1''$
ε_0
$q_1 = q$
$q_1' = \frac{2\varepsilon_2}{\varepsilon_2+\varepsilon_0} q_1$
ε_2
$q_1' = -\frac{\varepsilon_2-\varepsilon_0}{\varepsilon_2+\varepsilon_0} q_1$
ε_1
$q_1'' = -\frac{\varepsilon_1-\varepsilon_2}{\varepsilon_1+\varepsilon_2} q_1'$
$q_1''' = \frac{2\varepsilon_0}{\varepsilon_0+\varepsilon_2} q_1''$
$(a_0'+2ma)R_0$
$(a_0'+2a)R_0$
ε_0
$a_0'R_0$
ξ
r
ε_2
d
ε_1
$(a_0'+2a)R_0$
$(a_0'+2ma)R_0$
z

Fig. 5

$$\left(\frac{\delta f}{f_0}\right)_\omega = A\,\varepsilon_{333}\,E_1$$

$$\overline{E}_1 = \frac{1}{32}\frac{V}{R_0}\frac{\varepsilon_{33}+\varepsilon_0}{2\varepsilon_0}$$

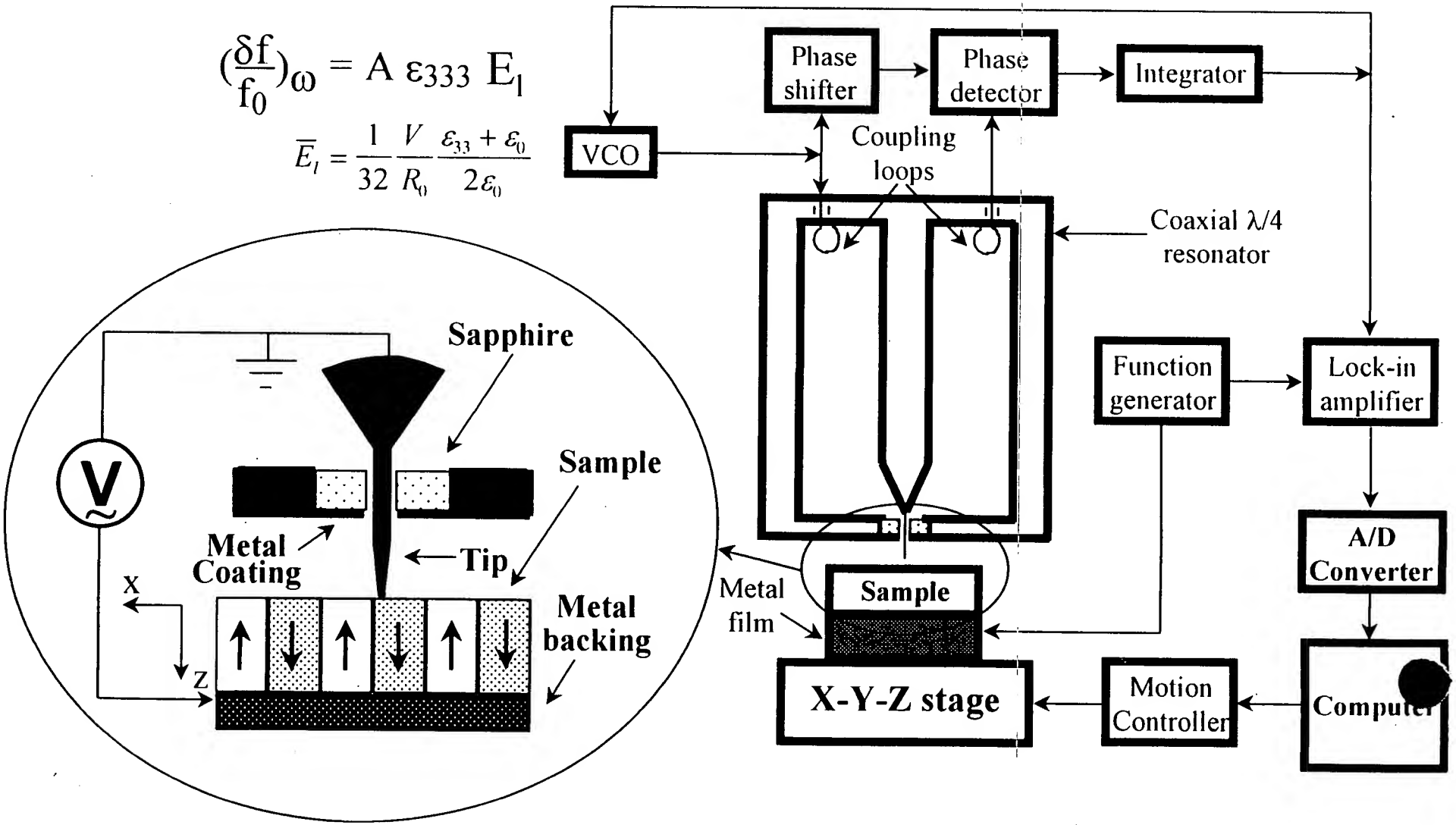
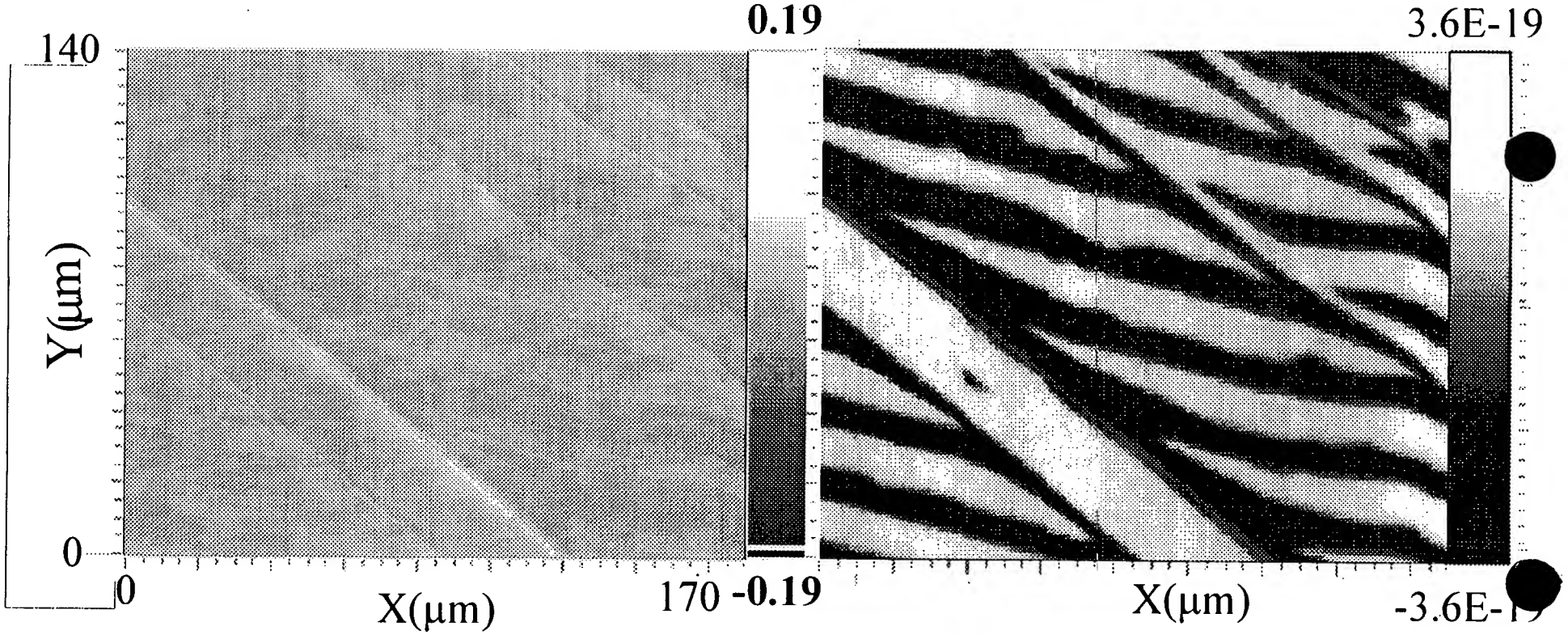


Fig. 6

$$\varepsilon_{33}(E_l) = \frac{\partial D_3}{\partial E_m} = \varepsilon_{33} + \varepsilon_{333}(E_l + E_m) + \frac{1}{2}\varepsilon_{3333}(E_l + E_m)^2 + \cdots$$

$\Delta\varepsilon$ ε_{333}(F/V)



Sensitivity $\Delta\varepsilon/\varepsilon \sim 10^{-3}$

Fig. 7

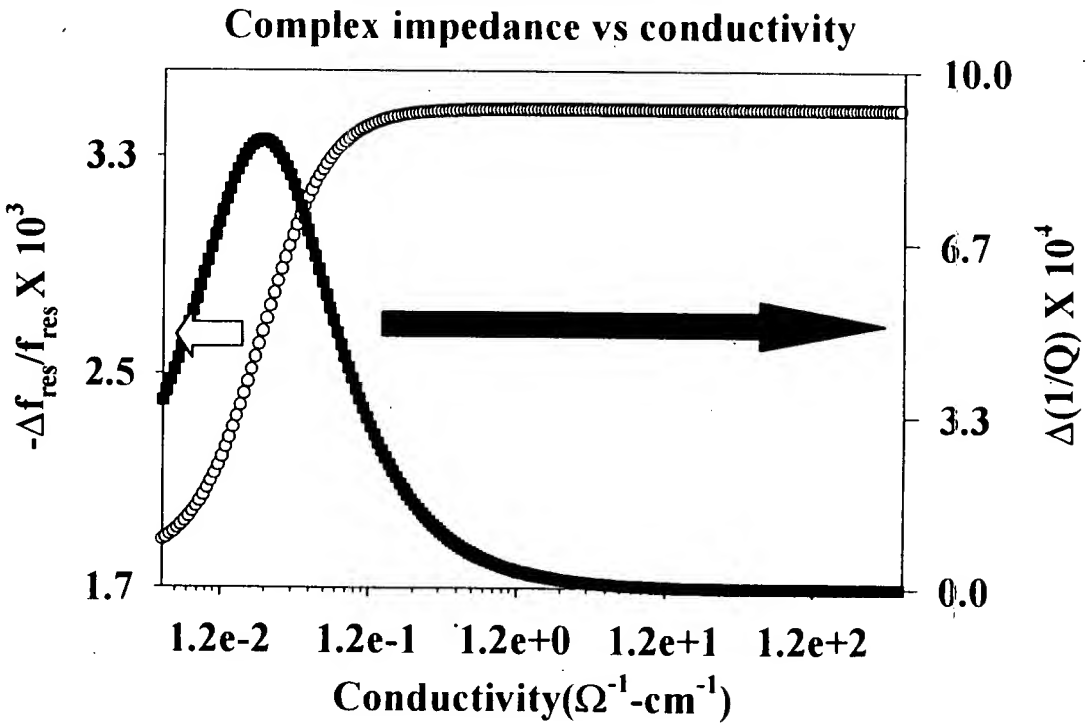

Complex impedance vs conductivity
10.0
6.7
3.3
0.0
3.3
2.5
1.7
$-\Delta f_{res}/f_{res}$ X 10^3
$\Delta(1/Q)$ X 10^{-4}
1.2e-2
1.2e-1
1.2e+0
1.2e+1
1.2e+2
Conductivity(Ω^{-1}-cm^{-1})

Fig. 8

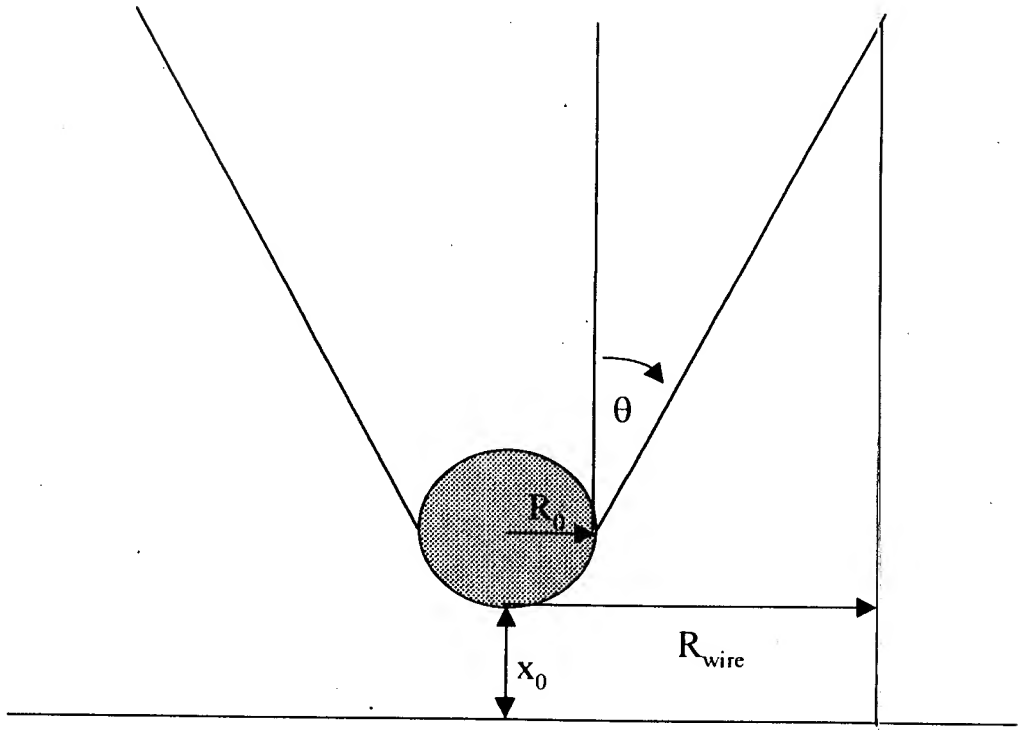


Fig. 9

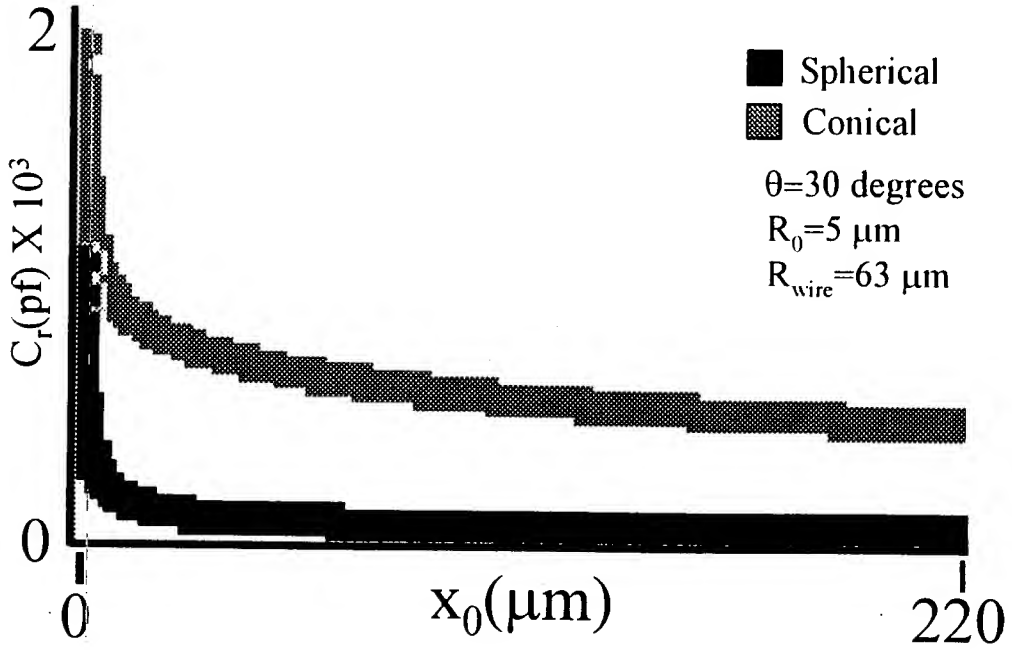

2
0
C_r(pf) X 10^3
0
x_0(μm)
220
Spherical
Conical
θ=30 degrees
R_0=5 μm
R_{wire}=63 μm

Fig. 10

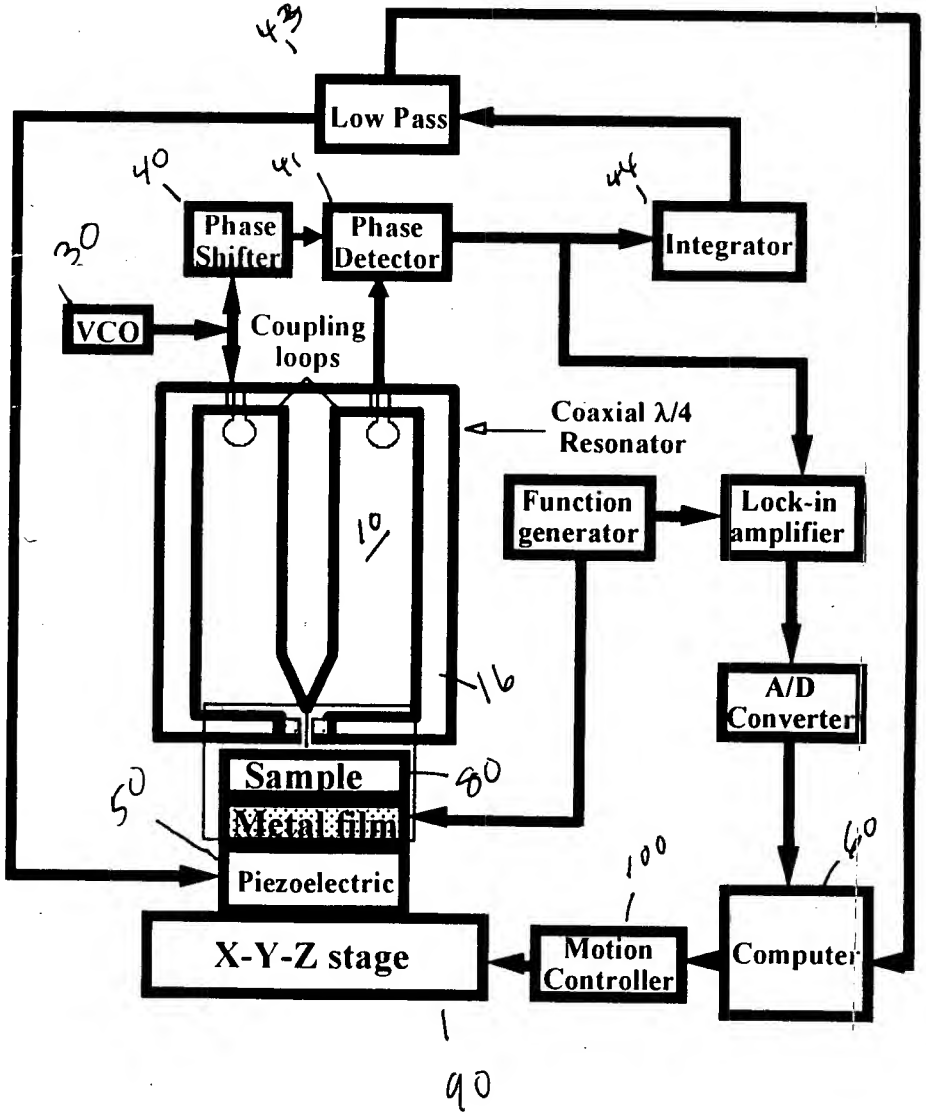

Low Pass
Phase Shifter
Phase Detector
Integrator
VCO
Coupling loops
Coaxial λ/4 Resonator
Function generator
Lock-in amplifier
A/D Converter
Sample
Metal film
Piezoelectric
X-Y-Z stage
Motion Controller
Computer
43
40
41
44
30
10
16
80
50
100
60
90

Figure 11

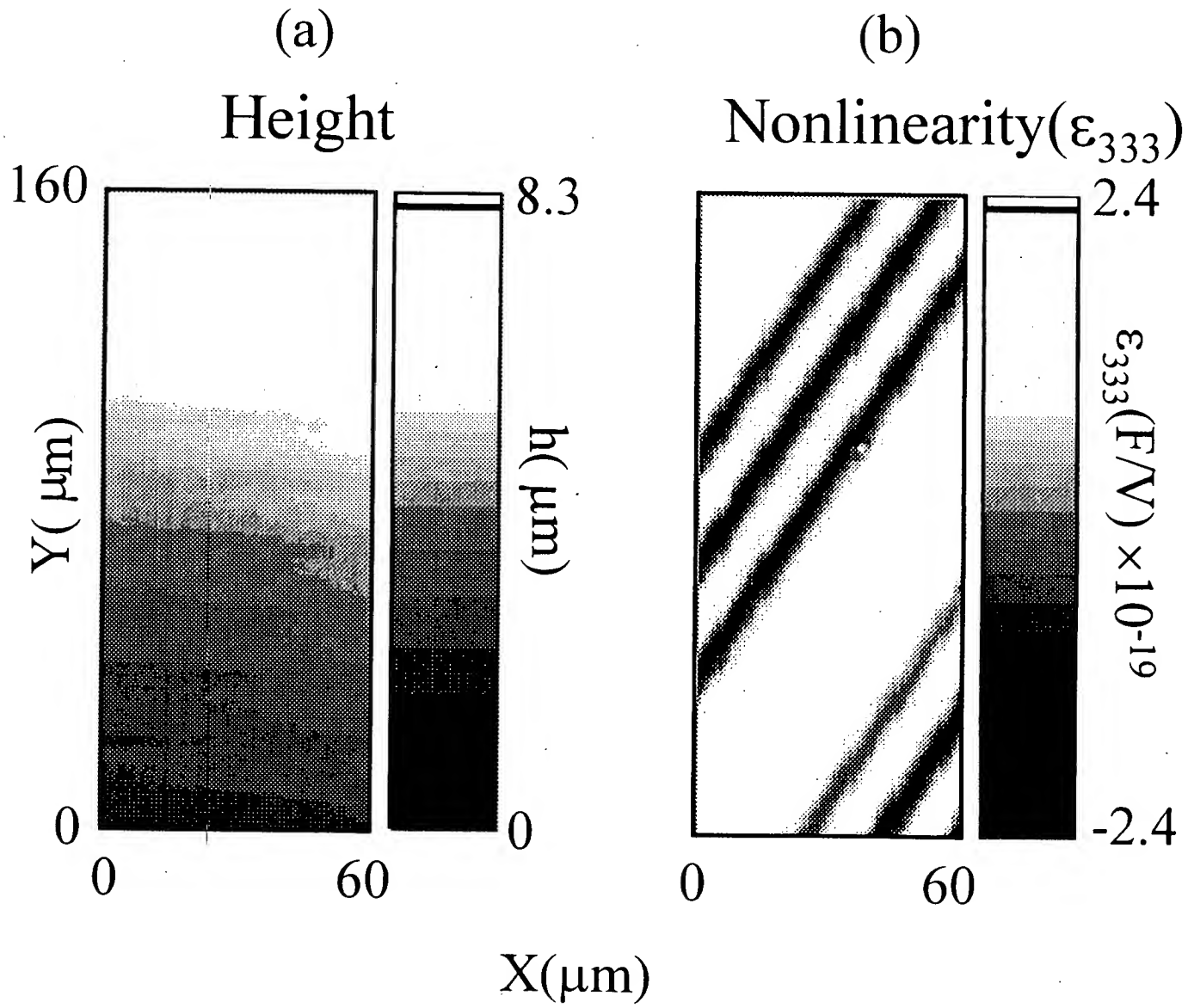

(a)
Height
160
8.3
Y(μm)
h(μm)
0
0
0
60
(b)
Nonlinearity(ε_{333})
2.4
ε_{333}(F/V) ×10^{-19}
-2.4
0
60
X(μm)

Figure 12

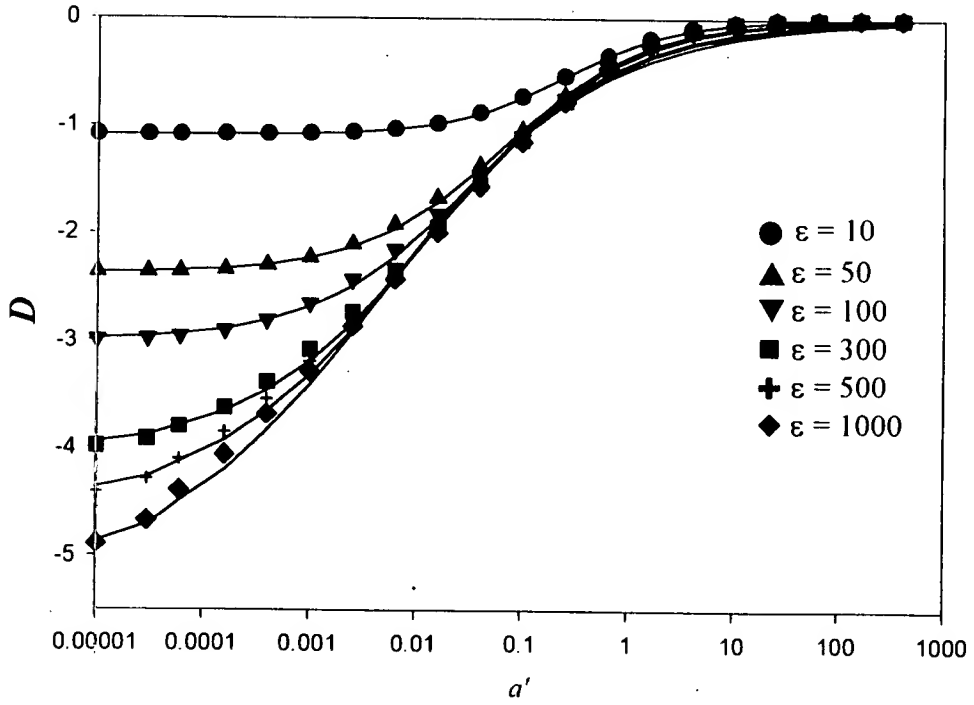

0
-1
-2
-3
-4
-5
D
0.00001
0.0001
0.001
0.01
0.1
1
10
100
1000
a'
ε = 10
ε = 50
ε = 100
ε = 300
ε = 500
ε = 1000

Fig. 13

Derivative signal (pf/μm) vs Tip-sample separation (μm)

FIG. 14 (a)

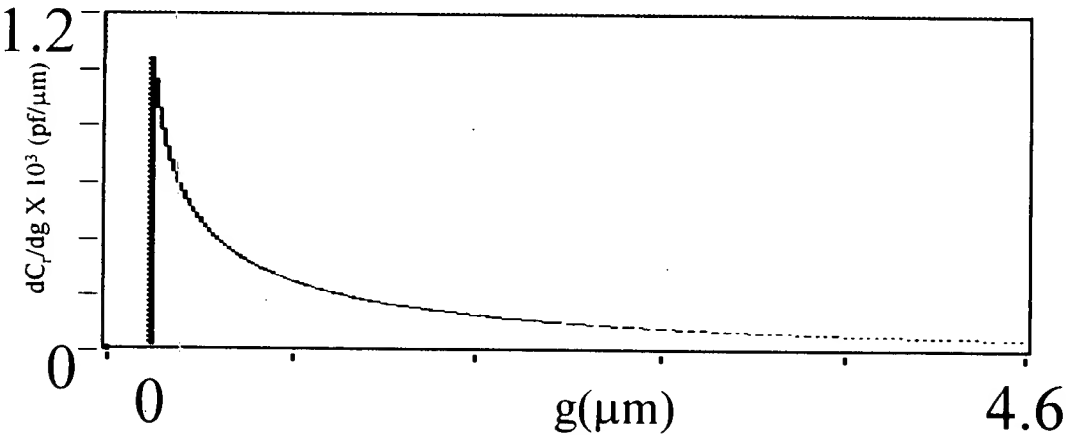


FIG. 14 (b)

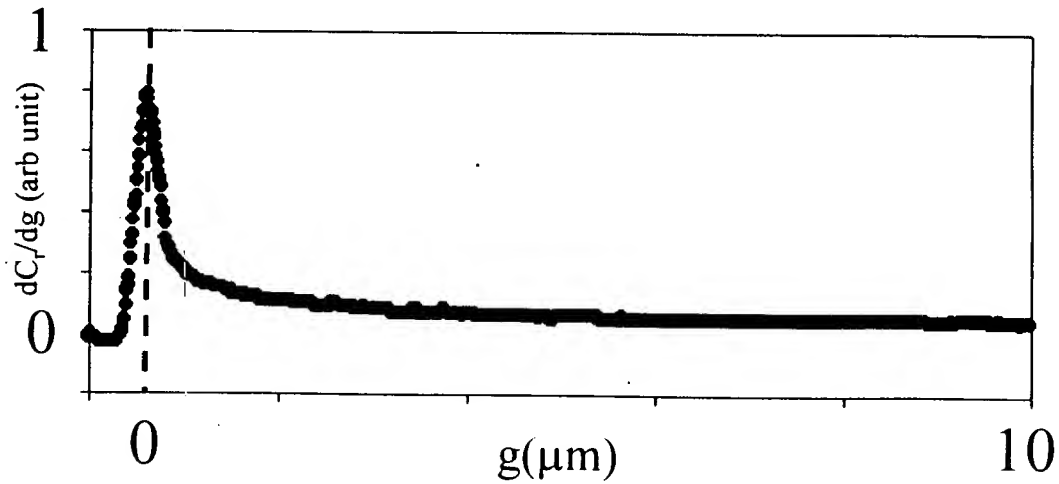


Fig. 14

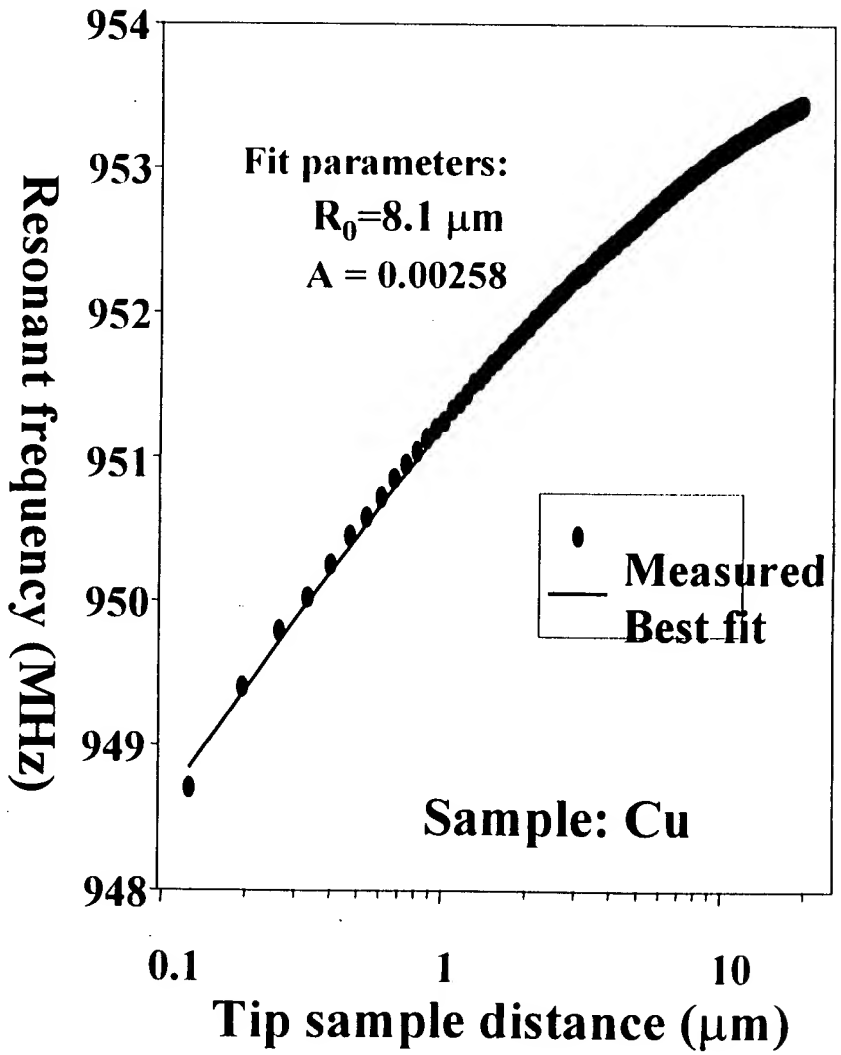

954
953
952
951
950
949
948
Resonant frequency (MHz)
Fit parameters:
R_0=8.1 μm
A = 0.00258
Measured
Best fit
Sample: Cu
0.1
1
10
Tip sample distance (μm)

Fig. 15

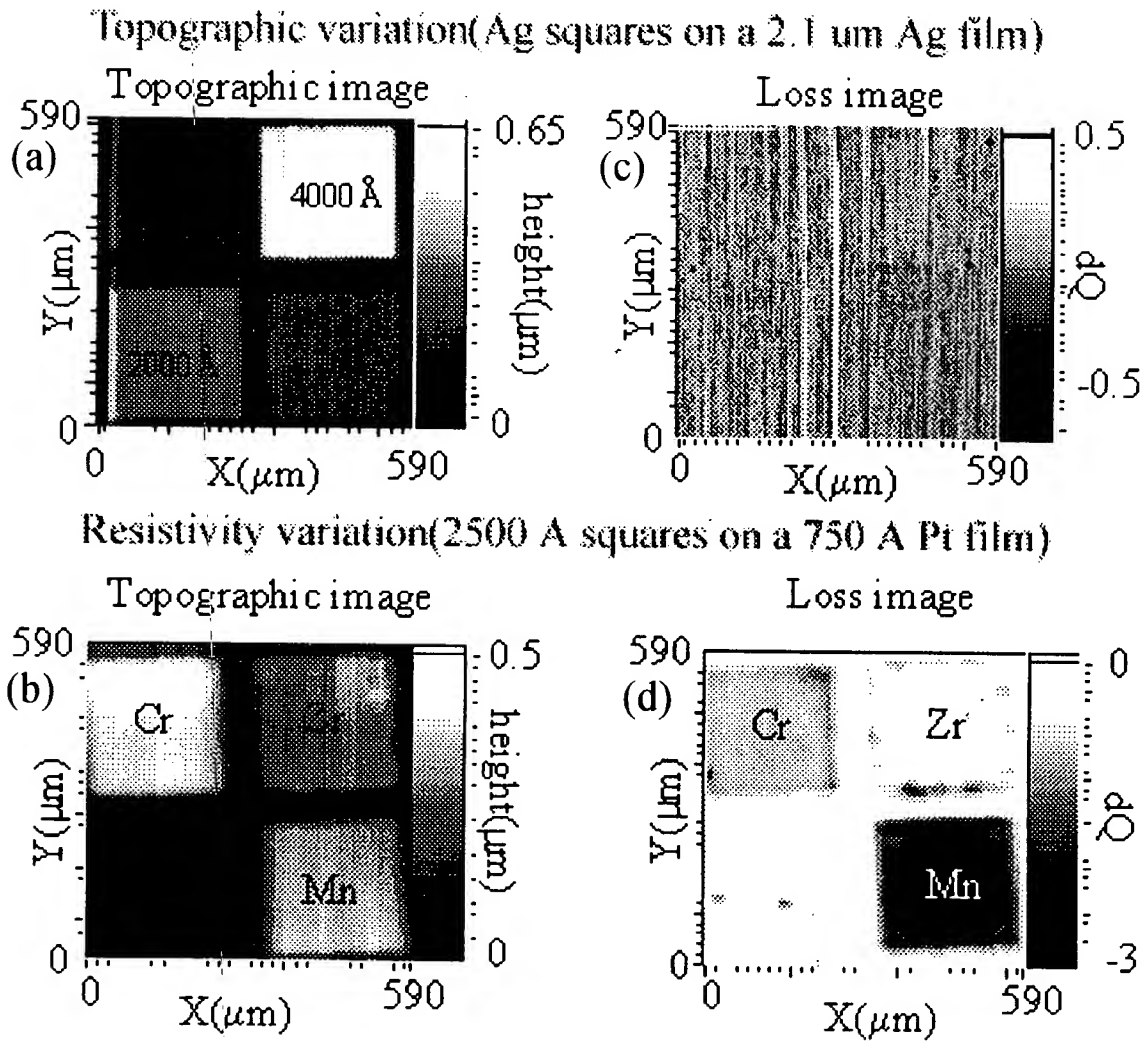

Topographic variation(Ag squares on a 2.1 um Ag film)
Topographic image
Loss image
(a)
(c)
4000 Å
2000 Å
590
0
0.65
0.5
-0.5
height(μm)
dp
Y(μm)
X(μm)
Resistivity variation(2500 A squares on a 750 A Pt film)
Topographic image
Loss image
(b)
(d)
Cr
Zr
Mn
0.5
-3
dQ

Fig. 16

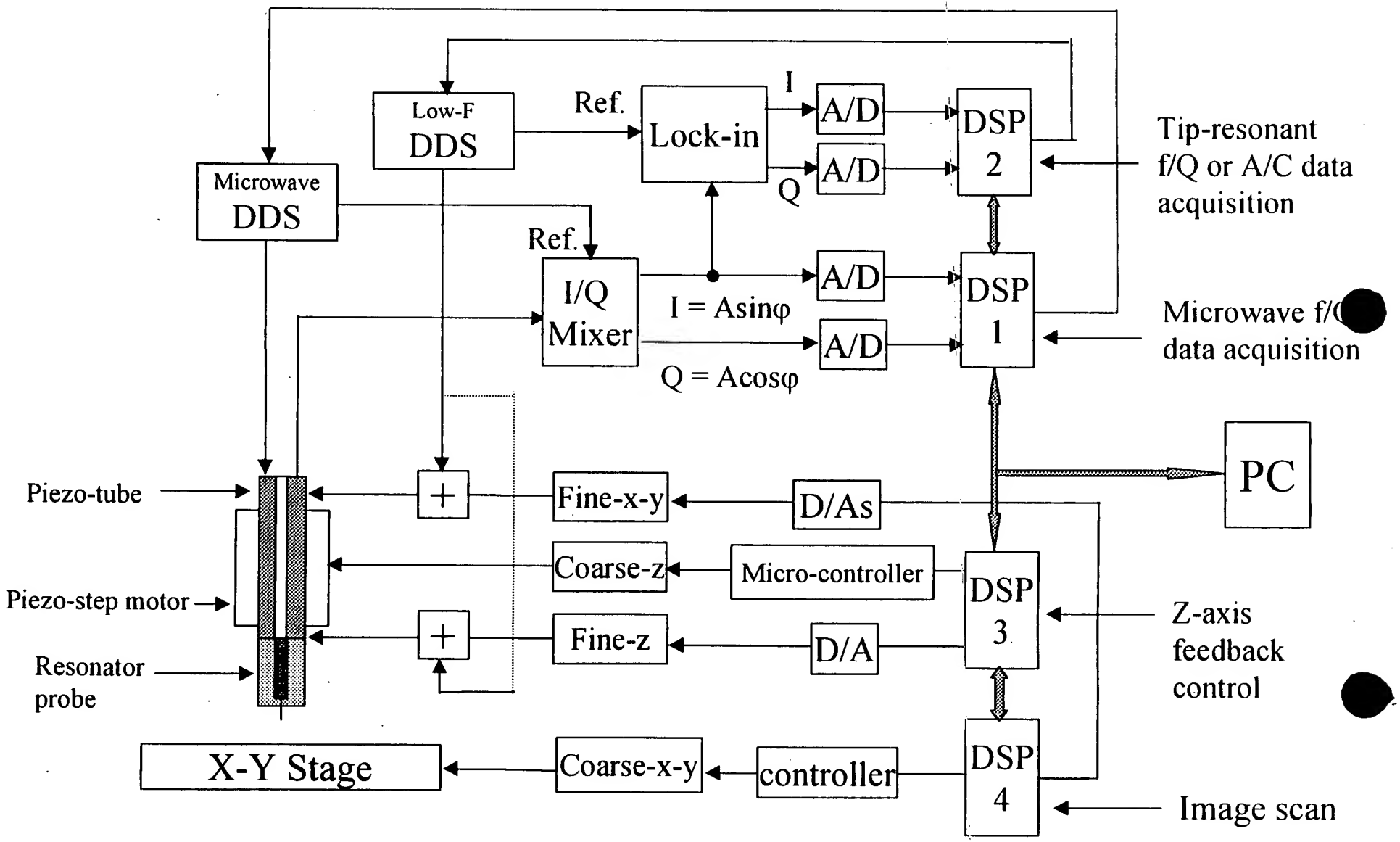

Low-F
DDS
Ref.
Lock-in
I
Q
A/D
A/D
DSP
2
Tip-resonant
f/Q or A/C data
acquisition
Microwave
DDS
Ref.
I/Q
Mixer
I = Asinφ
Q = Acosφ
A/D
A/D
DSP
1
Microwave f/Q
data acquisition
PC
Piezo-tube
Piezo-step motor
Resonator
probe
Fine-x-y
D/As
Coarse-z
Micro-controller
Fine-z
D/A
DSP
3
Z-axis
feedback
control
X-Y Stage
Coarse-x-y
controller
DSP
4
Image scan

Fig. 17

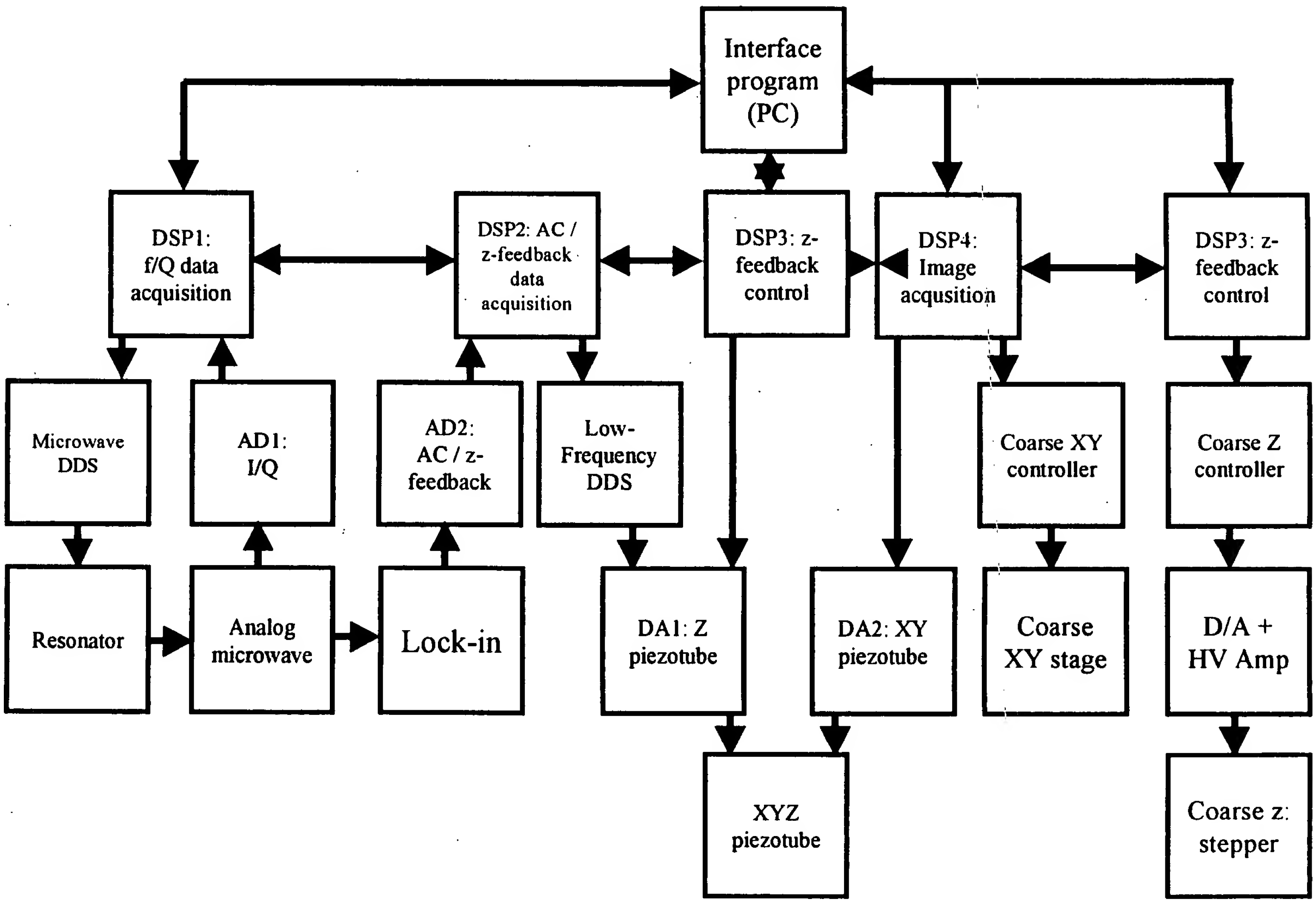

Interface program (PC)
DSP1: f/Q data acquisition
DSP2: AC / z-feedback data acquisition
DSP3: z-feedback control
DSP4: Image acqusition
DSP3: z-feedback control
Microwave DDS
AD1: I/Q
AD2: AC / z-feedback
Low-Frequency DDS
Coarse XY controller
Coarse Z controller
Resonator
Analog microwave
Lock-in
DA1: Z piezotube
DA2: XY piezotube
Coarse XY stage
D/A + HV Amp
XYZ piezotube
Coarse z: stepper

Fig. 18

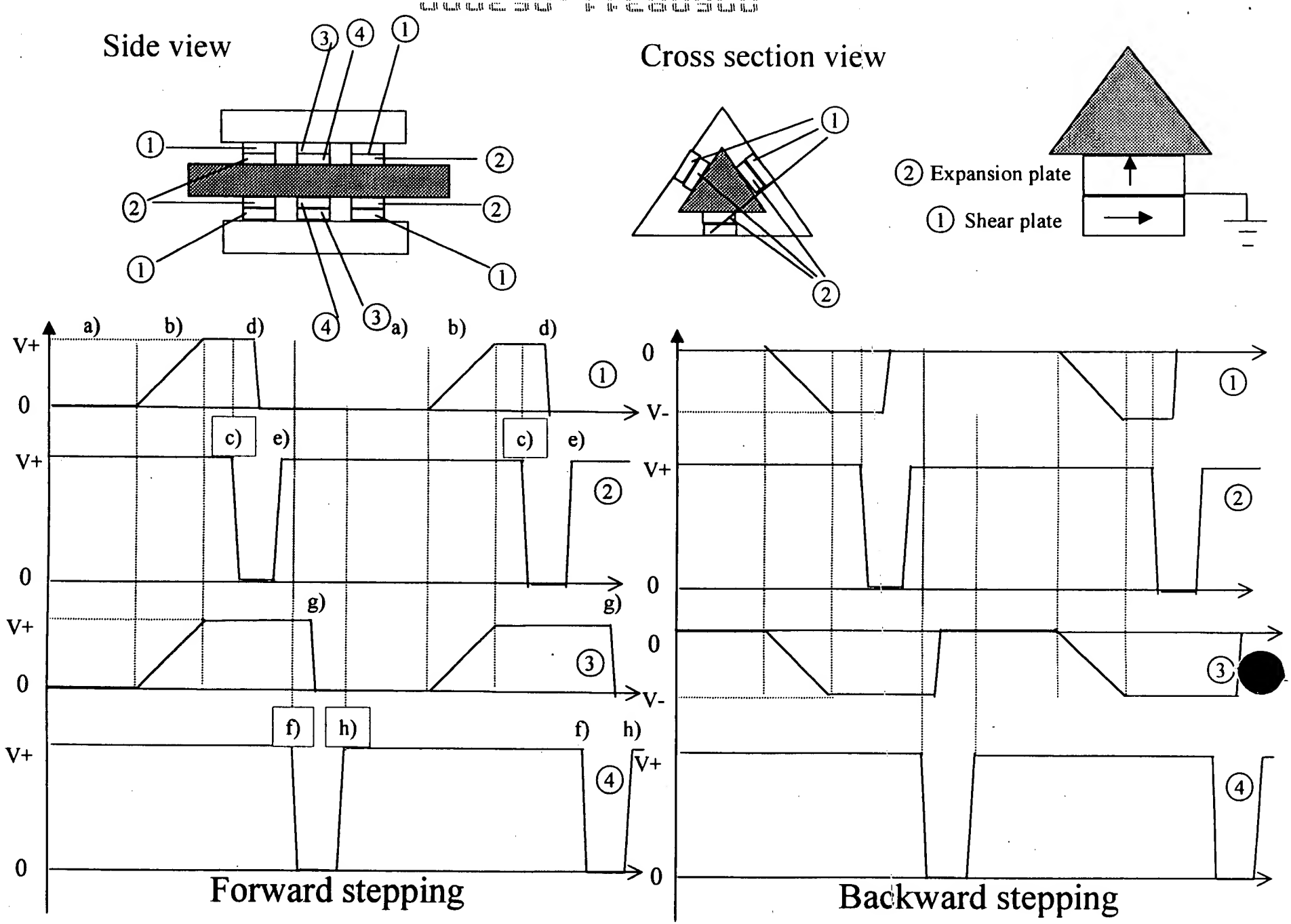

Side view
Cross section view
② Expansion plate
① Shear plate
V+
0
V-
a)
b)
c)
d)
e)
f)
g)
h)
Forward stepping
Backward stepping

Figure 19.

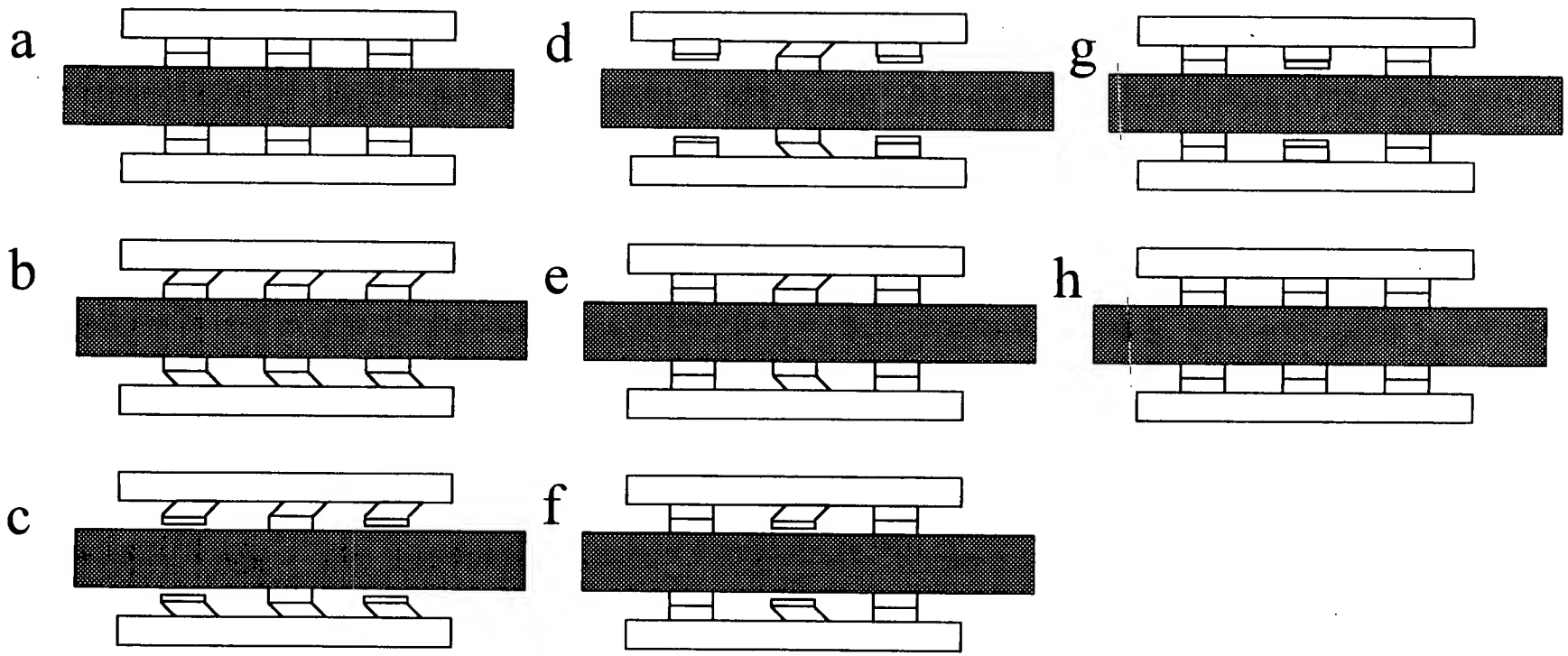


Figure 20.

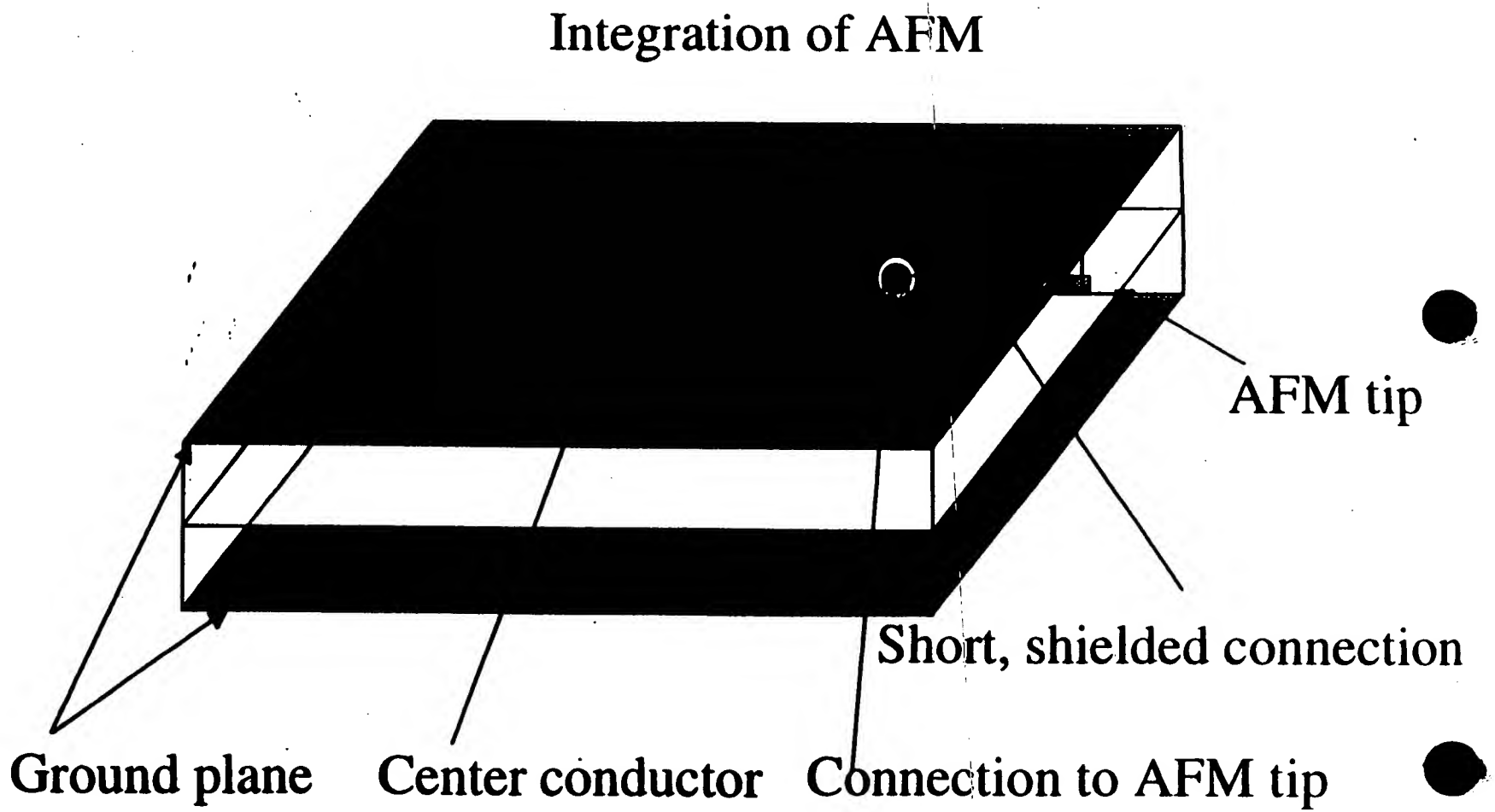


Figure 21.

Single Crystal Measurement

Material	Measured ε_r	Reported ε_r	Measured tanδ	Reported tanδ
YSZ	30.0	29	1.7×10^{-3}	1.75×10^{-3}
$LaGaO_3$	23.2	25	1.5×10^{-3}	1.80×10^{-3}
$CaNdAlO_4$	18.2	~19.5	1.5×10^{-3}	$0.4 - 2.5\times10^{-3}$
TiO_2	86.8	85	3.9×10^{-3}	4×10^{-3}
$BaTiO_3$	295	300	0.47	0.47
$YAlO_3$	16.8	16	-	8.2×10^{-5}
$SrLaAlO_4$	18.9	20	-	-
$LaALO_3$	25.7	24	-	2.1×10^{-5}
MgO	9.5	9.8	-	1.6×10^{-5}
$LiNbO_3$(X-cut)	32.0	30	-	-

Table 1

	SEMM (1GHz)		Interdigital Electrodes (1GHz)	
Films	ε_r	tan δ	ε_r	tan δ
$Ba_{0.7}Sr_{0.3}TiO_3$	707	0.14	750	0.07
$Ba_{0.5}Sr_{0.5}TiO_3$	888	0.19	868	0.10
$SrTiO_3$	292	0.02	297	0.015
$Ba_{0.24}Sr_{0.35}Ca_{0.41}TiO_3$	150	0.05		
$Ba_{0.25}Sr_{0.35}Ca_{0.4}TiO_3$	240	0.05		

Table 2